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TITLE THERMOPHYSICAL PROPERTIES OF LIQUID NIOBIUM

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# THERMOPHYSICAL PROPERTIES OF LIQUID NIOBIUM*

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## I. INTRODUCTION

Thermophysical properties of most liquid metals are difficult to measure because of the very high temperatures and pressures required, but they are important for several reasons. These include understanding the fundamental physics of liquid metals and experimental modeling and design of exploding wires, foils and fuses. The melting points of all but a few metals are at high temperatures, with many exceeding 2000 K. The critical points of most metals exceed temperatures and pressures that may be easily achieved in static high-pressure systems. Because of the limitations on temperatures that may be reached in static high-pressure experiments, various dynamic techniques have been developed to study liquid metals. We use a resistive pulse heating method in which a cylindrical wire-shaped sample is made to expand along an isobaric path.[1] During an experiment the sample is heated, made to melt, and enthalpy, temperature, and specific volume are measured. After the liquid end state is reached, a single sound speed measurement per experiment is made. From these fundamental properties, other properties such as thermal expansion coefficient, bulk modulii, and compressibilities may be calculated.[2] Here we report measurements that we have recently made on liquid niobium.

## II. EXPERIMENTAL DETAILS

The experimental technique and apparatus is described in detail elsewhere.[1] Briefly, a wire-shaped sample (1 mm × 25 mm) is contained in a high-pressure vessel filled with argon gas. The pressure vessel has a maximum pressure capability of 10 kbar, and has four optical ports for diagnostics. A capacitor bank discharge provides electrical current of sufficient amplitude ($\sim 15 \times 10^3$ amperes) to resistively self heat the sample to high-temperature liquid states. The sound-speed measurement is done using a non-contacting technique.[2] A 0.1-Joule ruby laser pulse is focussed onto a small spot on one side of the sample generating a sound wave that propagates across the sample diameter. The arrival of this disturbance at the side opposite the source is detected with an optical technique, and the average velocity across the sample may be calculated.

## III. DISCUSSION

Results for our measurements on liquid niobium are shown in Table I. As may be seen we present values of temperature, volume, electrical resistivity, and enthalpy at a pressure of 2 Kb. Figure 1 presents the ratio $V/V_0$ of volumes plotted against enthalpy. Shown for comparison are the values measured previously by Shaner[3] and Gallob.[4] As can be seen we agree fairly well with the results of Shaner et al. Our estimated uncertainty in volume is ± 3% and that in enthalpy ±2%. The best fit to this data is given by:

$$V/V_0 = 1.01762 + 3.4785 \times 10^{-2}\, H + 3.8108 \times 10^{-3}\, H^2$$

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where 1.13 MJ/kg $\leq$ H $\leq$ 2 MJ/kg.

We have plotted our measured enthalpies versus temperature in Fig. 2 with a calculated value of specific heat $C_p$ of 497 J/Kg·K. For comparison the value of Shaner et al. is 610 J/Kg·K, that of Gallob 513 J/kg·K, and that of Cezairliyan[5] 439 J/kg·K. The wide range in values is probably due to the fact that $C_p$ depends upon temperature, the least accurate of all measured quantities. The least squares fit to this temperature data is:

$$H = -0.202 + 4.9667 \times 10^{-4}\ T$$

where $T$ is in $K$, and 2750 $\leq$ T $\leq$ 4450. Temperatures are estimated to be accurate to $\pm5\%$. From the thermal arrest "plateau" in our pyrometer records we find enthalpy values of 0.85 MJ/kg at the beginning of melt, and 1.13 at the end of melt, leading to a heat of fusion value of 0.28 MJ/kg.

Shown in Fig. 3 are our results for electrical resistivity plotted along with those of Shaner and Gallob. We agree very will with Gallob, and this is somewhat surprising since we do not agree well with their measured volumes. Our lack of agreement with the results of Shaner for resistivity is not understood. The fit for this data is

$$\rho_{el} = 8.6893 \times 10^{-7} + 2.01398 \times 10^{-7}\ H \quad ,$$

where 1.13 MJ/kg $\leq$ H $\leq$ 2 MJ/kg, and $\rho_{el}$ is in $\mu$-$\Omega$-m.

Sound velocities have been measured in liquid niobium over a wide range of densities, and these are shown in Fig. 4. We have plotted sound velocity against density to display the linear behavior as seen in all metals measured previously.[6,7] The best fit to our sound velocity data is given by:

$$C = -3.8669 + 1.1432\ \rho \quad ,$$

where $C$ is in km/s, and 6.79 gm/cm$^3$ $\leq \rho \leq$ 7.59 gm/cm$^3$.

When sound velocity data is combined with the other quantities measured during an experiment, many additional thermodynamics properties may be calculated as shown previously.[2] As an example of this, we may find the adiabatic bulk modulus:

$$B_s = \rho\left(\frac{\partial P}{\partial \rho}\right)_s = \rho c^2$$

from other measured quantities, and the adiabatic compressibility from

$$K_s = \frac{1}{B_s} \quad .$$

These calculated values of $B_s$ and $K_s$ are shown in Fig. 5. As previously done for lead, it is now possible to calculate the Grüneisen parameter, $\gamma_g$, the isothermal bulk modulus and compressibility, the specific heat at constant volume $C_v$, and the ratio $\gamma = C_p/C_v$.

## REFERENCES


[1] G. R. Gathers, J. W. Shaner, and R. K. Brier, Rev. Sci. Instrum. 47:471 (1976).

[2] R. S. Hixson, M. A. Winkler, and J. W. Shaner, High Temp./High Press., 17:267 (1985).

[3] J. W. Shaner, G. R. Gathers, and W. M. Hodgson, Proceedings of the 7th Symposium on Thermophysical Properties, A. Cezairliyan Ed. (1977).

[4] R. Gallob, H. Jäger, and G. Pottlacher, High Temp./High Press. 17:207 (1985).

[5] A. Cezairlyan and J. L. McClure, Int. J. Therm. 8:803 (1987).

[6] R. S. Hixson, M. A. Winkler, and J. W. Shaner, High Temp./High Press. 18:635 (1986).

[7] R. S. Hixson and M. A. Winkler, LA-UR 88-1852 (1988).


Table I. Thermophysical properties of liquid niobium.

| H(MJ/kg) | T(K) | $V/V_0$ | $\rho_{el}(\mu\text{-}\Omega\text{-}m)$ |
|---|---|---|---|
| 1.13 | 2750 | 1.107 | 1.096 |
| 1.2 | 2850 | 1.112 | 1.115 |
| 1.3 | 2975 | 1.128 | 1.139 |
| 1.4 | 3200 | 1.143 | 1.151 |
| 1.5 | 3375 | 1.153 | 1.16 |
| 1.6 | 3650 | 1.170 | 1.18 |
| 1.7 | 3825 | 1.187 | 1.208 |
| 1.8 | 4050 | 1.204 | 1.227 |
| 1.9 | 4225 | 1.225 | 1.261 |
| 2.0 | 4450 | 1.237 | 1.275 |

$V_0 = 1.17 \times 10^{-4}\ m^3 kg$
$P = 2$ kb

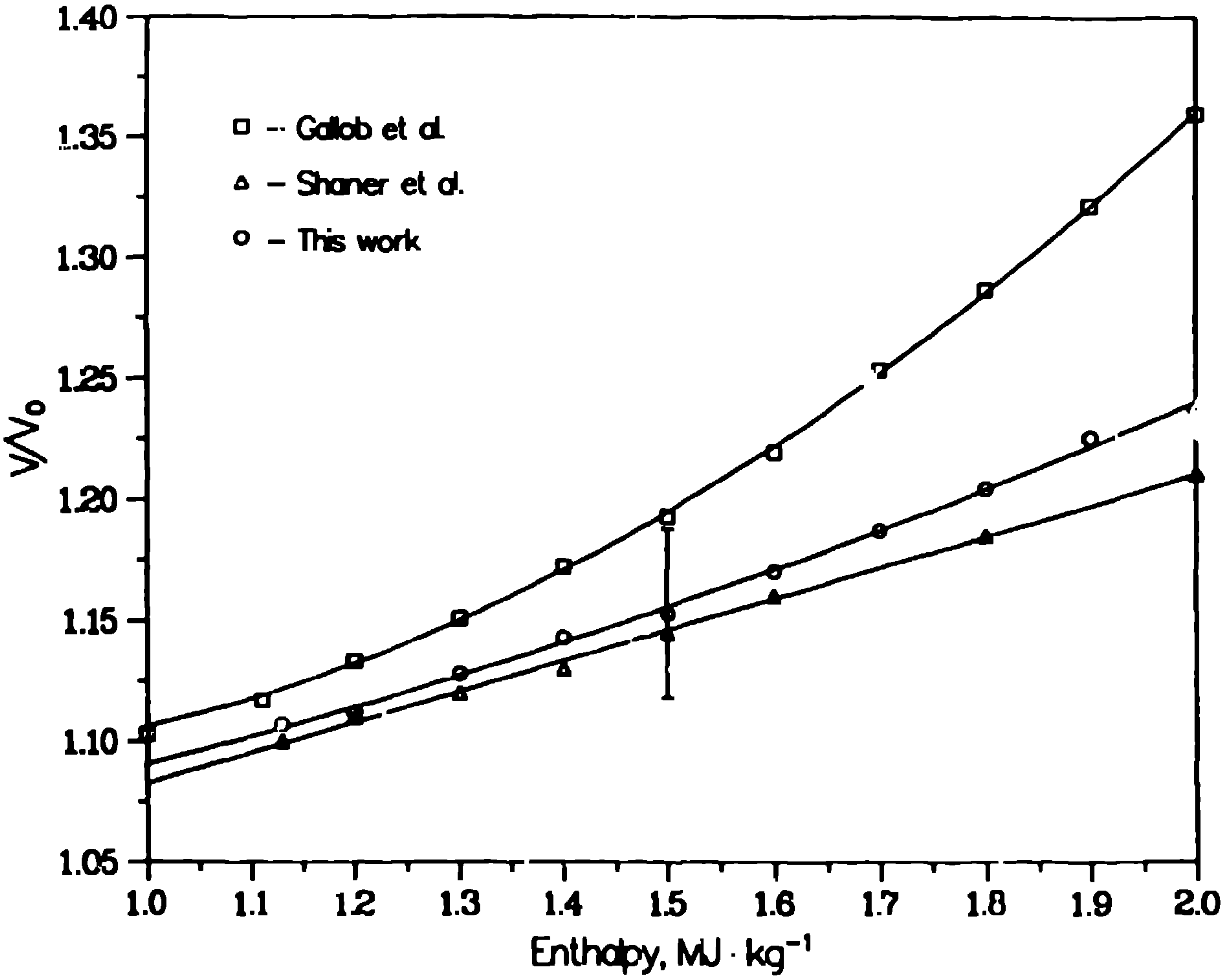


Fig. 1. Volume plotted against enthalpy for liquid niobium.

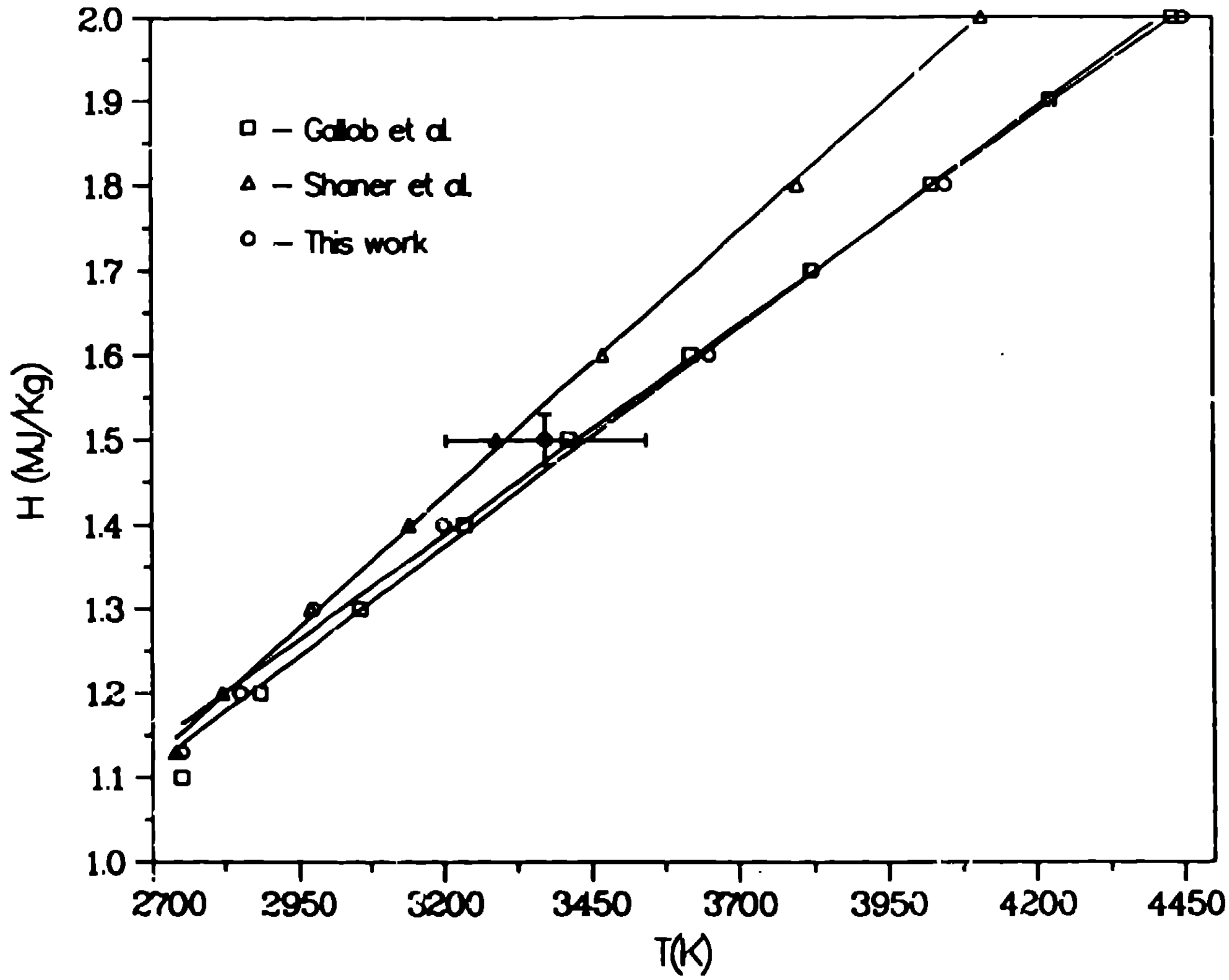


Fig. 2. Enthalpy versus temperature.

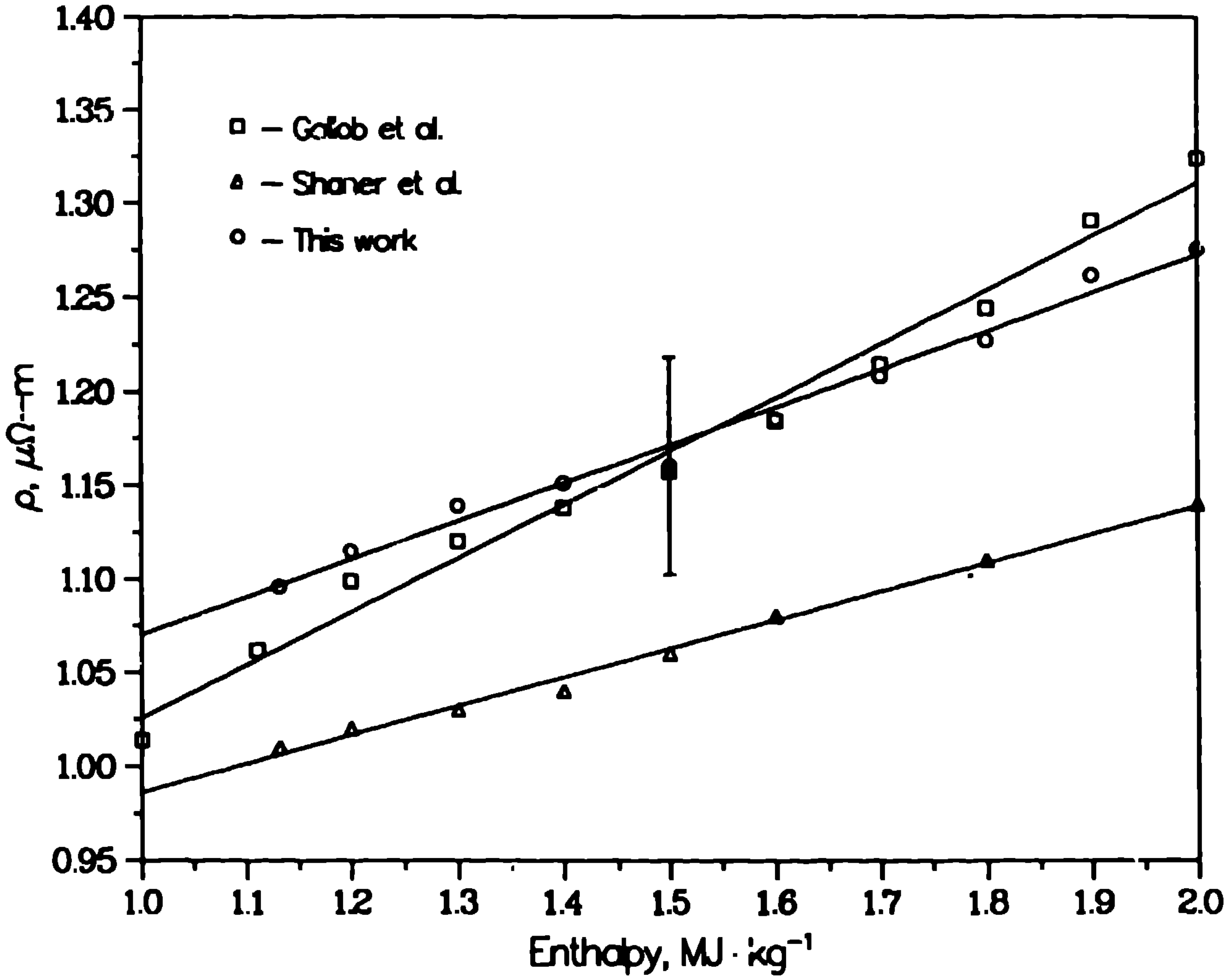


Fig. 3. Electrical resistivity plotted against enthalpy.

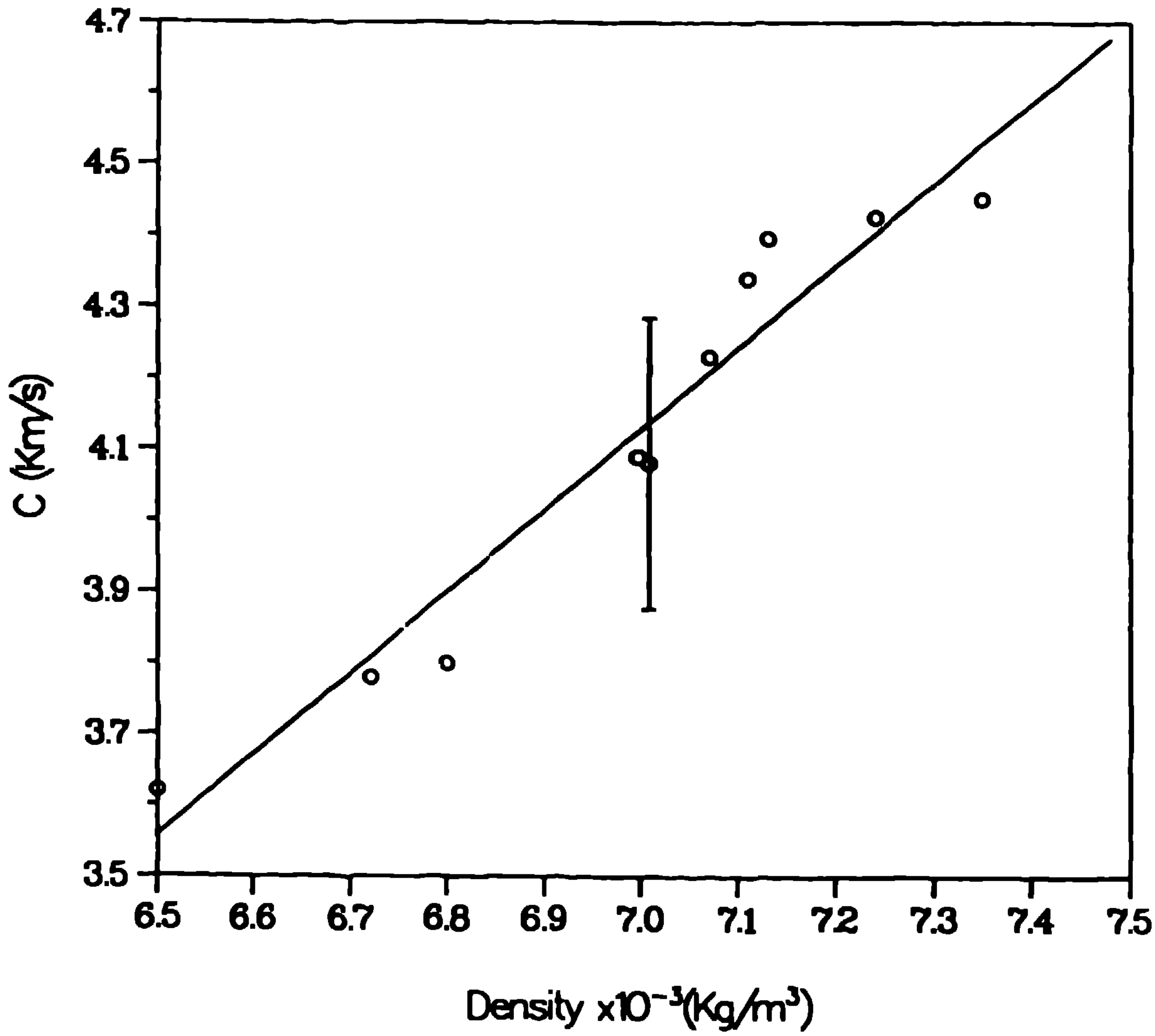


Fig. 4. Measured sound velocities in liquid niobium.

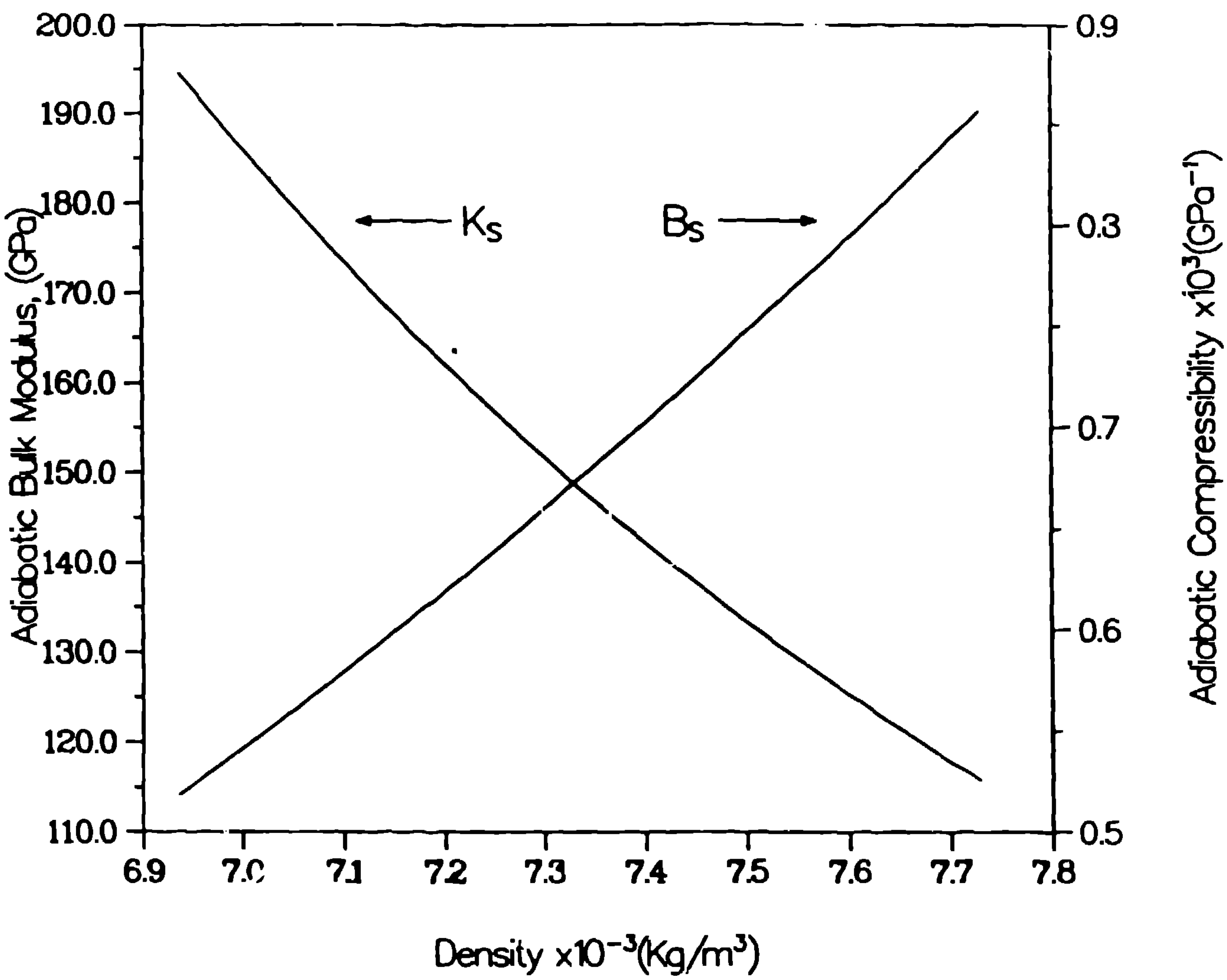


Fig. 5. Calculated values of adiabatic bulk modulus $B_s$ and compressibility $K_s$.